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Systems Evaluation Branch
Monthly Precipitation Verification

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This is an unreviewed manuscript, primarily
intended for informal exchange of information
among NMC staff members.

INTRODUCTION

The objective of Systems Evaluation Branch monthly precipitation program is to monitor the quality of precipitation forecasts from NMC's operational models. In order to maintain a reasonably current evaluation program and produce a meaningful verification system, station networks were carefully selected and quality control procedures established.

John M. Horodeck archived station precipitation observations and operational model forecasts and designed the verification system. Phil Hovey was originally responsible for quality control, Chuck Burley continued it and more recently Joe Johnson has assisted in all phases of evaluation.

STATION VERIFICATION NETWORK

Numerical model precipitation forecasts are areal estimates of precipitation. Observed precipitation amounts, however, are available from various types of weather observing stations. These stations are not sufficiently numerous nor uniformly distributed over the U. S. to adequately depict observed areal precipitation amounts.

Station networks, using a number of reasonably distributed stations were selected. The size of the network depended upon model mesh-lengths as well as a consideration of physiographic sub-divisions of the United States.

FIGURES Ia-c, are the 90-, 101- and 190-station verification networks. The foothills of the Rocky Mountains represents the major west (WEST) and east (EAST) divisions of these networks. The 90-station network was in use long before the verification program was designed. It is an extension of Forecast Division's (FD) 60-station network. The arrows between Kalispell (FCA) and Missoula (MSO), Montana and between Burns (4BW) and Klamath Falls (4LW), Oregon indicate that they are interchangeable within the network (observation station elimination is a caprice of the political weather situation).

The 90-station network has two Canadian stations. Canadian reports are usually not available during normal daily data archiving. The 101- and 190-station networks are composed of U. S. stations only and replaced the 90-station net in 1979.

QUALITY CONTROL

Observed six-hourly accumulated precipitation amounts for the periods ending at 18Z the previous day and 00Z, 06Z and 12Z of the current day are archived daily. A printout of these six-hour amounts, 12-hour totals using 18Z plus 00Z and 06Z plus 12Z observations and a 24-hour total of all four periods is available each day.

All reports from each station used in the verification networks are checked. These reports can be incorrect for any reason, including a failure to report precipitation. Virtually any positive amount can be correct. Also, numerous reports are not available by data cut-off time because of delays that are often associated with "bad" weather conditions. In addition, data can be lost due to a failure in the automated archiving system.

The quality control procedure uses manually plotted (up-dated with delayed reports and corrections) 24-hour accumulation maps as well as six-hourly maps prepared daily by Heavy Precipitation Branch.

Fifteen percent of the total observation data base had to be corrected daily during September, October and November 1978. Also, about three times during each month, all stations had to be manually retrieved due to archiving failures. For September, October and November 1980 corrections averaged 20.8, 13.7 and 15.9% of the archived observations respectively. These figures include three data loss days in September and two in October.

Precipitation is usually observed over only a small percentage of the verification area. This percentage is similar to the average daily number of changes that are normally required to correct the observation data base. Thus, even though quality control is time consuming and tedious it does insure that each forecast period has a complete network of stations and that every day of the month is available for verification.

VERIFICATION STATISTICS

This report summarizes monthly statistics from August to November 1978 and from February 1979 to February 1982. The 90 station network was used until July 1979. In August 1979, coarse-mesh (101 stations) and fine-mesh (190 stations) networks were introduced.

Numerical models in operation during the evaluation period were:

1. Fine-Mesh (53x57 point, 190.5KM grid true at 60°N)

LFMII: Limited-Area Fine-Mesh Model with 127KM increment;

August to November 1978 and February 1979 to May 1981

LFM: Limited-Area Fine-Mesh Model, Fourth Order; June 1981
to February 1982

2. Coarse-Mesh (65x65, 381KM grid true at 60°N)

7LPE: Seven-Layer Primitive Equation Hemispheric Fine-Mesh Model; August to November 1978 and February 1979 to August 1980

SMG30: Spectral Global Model, 30 Mode, 12 Layers; September 1980 to February 1982

Note that fine-mesh and coarse-mesh models do not have coincident grid point locations. The above classification is based on archived data and does not represent the complete resolution of model grid locations available during actual computer forecast operation.

For each verification network, composed of N stations, the total number of stations forecast (F) compared to the number observed to have precipitation (O) yield the number of correctly forecast stations, hits (H). Conventional precipitation verification statistics are:

$$\text{Precipitation Threat Score: } \text{TSP} = H / (F + O - H) \quad (1)$$

$$\text{No-precipitation } \text{TSNP} = [N - (F + O - H)] / (N - H) \quad (2)$$

$$\text{Bias: } \text{BIAS} = F / O \quad (3)$$

Both TSP and BIAS vary considerably with the occurrence of precipitation.

To assist in the interpretation of TSP and BIAS trends an estimate of average observed rainfall is also calculated.

$$\text{Percentage Rainfall Coverage: } \%R = O / N \quad (4)$$

Monthly statistics are presented for WEST and EAST divisions of the verification networks and never for the total net alone. Model forecast characteristics differ significantly over these two divisions. For example, in Table I, December 1976 plus January 1977, TSP and BIAS for EAST and WEST divisions of the 90-station net are shown for the original Limited-Area Fine-Mesh Model. Over the EAST, this model had a very dry bias at 12 hours and rather dry biases for the remainder of the forecast periods. Over the WEST, however, biases increased rapidly with time to very large values at 48 hours. Similar characteristics were true for the operational coarse-mesh model, the Six-Layer PE. Table I also includes March 1978 statistics for the 7LPE.

The use of total network statistics can conceal important model characteristics. In addition, increase/decrease in TSP is often interpreted as model improvement/degradation, even without actual model change, rather than simply the effect of rainfall distribution. For example, compare LFMII forecasts for February 1980 with February 1981 using the 190-station net:

	%R	24HR TSP/BIAS	36HR TSP/BIAS
FEB80	18.4%	.419/1.37	.376/1.50
FEB81	18.6%	.482/1.26	.400/1.23

There appears to be a large difference in the quality of model forecasts between the two years for apparently similar average observed rainfall conditions. Statistics for the EAST (128 stations) and WEST (62 stations) divisions of the network are:

EAST ...	%R	24HR TSP/BIAS	36HR TSP/BIAS
FEB80	16.1%	.397/0.98	.364/1.04
FEB81	20.3%	.521/1.03	.441/0.94

WEST...	%R	24HR TSP/BIAS	36HR TSP/BIAS
FEB80	23.2%	.441/1.92	.387/2.17
FEB81	15.2%	.413/1.90	.332/2.04

It is clear that similarity in %R distribution between the two years for the total 190-station verification area was the result of a combination of opposite %R over the two divisions. Larger %R over the EAST in 1981 resulted in larger overall TSP.

Another important point should be made about station networks. Consider the following statistics for December 1980:

190-station network	24HR TSP/BIAS
LFMII	.398/1.27
101-station network	
SMG3C	.373/1.00
60-station network (FD)	
LFMII	.390/1.09
SMG3C	.448/0.83

The 60-station network uses only about two-thirds of the coarse-mesh forecast grid points over its verification area. A fortunate set of circumstances resulted in a much larger score, even larger than that for the LFMII, using this network for the SMG3C. It is clear that meaningful statistics evaluating model performance must be calculated from station networks that are reasonably distributed over the verification area.

There are insufficient number of stations, non-uniformly distributed, to setup an appropriate fine-mesh network. The fine-mesh net, 190 stations, has about one station for every two fine-mesh model forecast grid points. The 101-station net has one station for about every four grid points. Fine-mesh model TSP and BIAS trends are correctly shown using statistics from either network. Actual TSP values are slightly lower using more stations. If a completely fine-mesh net is used, TSP values would be slightly smaller still.

On the other hand, the 101-station net has as many stations as coarse-mesh forecast locations. If a fine-mesh net is used, TSP and BIAS trends will still be similar, but TSP values will be smaller. This decrease is unrelated to model performance. It results from multiple use of many forecast grid points. This is an incorrect use of station networks.

CHARACTERISTICS OF MODEL PRECIPITATION FORECASTS

Important changes to operational model precipitation forecast attributes occur primarily with model replacement and/or incorporation of new precipitation parameterization methods. The different models in operation during the verification record period have already been mentioned. A major change in the convective precipitation method was introduced into the LFMII in June 1979 and into the 7LPE in October 1979. These changes are noted in TABLES IIa-e which are monthly statistics (TSP, BIAS, %R) for the EAST and WEST divisions of the verification networks. Twelve months are presented on each table, starting with December of the previous year through November of the following year. A summary (includes TSNP) by seasons is presented in TABLES IIIa-b for fine-mesh and coarse-mesh models respectively.

Major precipitation forecast characteristics can be illustrated by plotting some of the data presented in the seasonal tables. Fine-mesh model 12 and 48 hour TSP and BIAS plus %R are shown in FIGURE IIa for the EAST division. If maximum TSP was not observed at 12 hours it (max value) is denoted by an x. The LFMII had 12 hour biases that were wet in summer, relatively wet during transition seasons. These biases decreased with time and tended to be near unity by 48 hours. The new convective method introduced in June 1979 was responsible for the overall increase in biases especially at 12 hours (compare autumn 1978, spring 1979).

Fourth-order LFM 12 hour biases are extremely wet in summer and fall. Biases decrease, but continue to be relatively wet at 48 hours. In winter, the bias trend reverses. Relatively wet biases are observed at 48 hours.

In general, TSPs are small during summer. Precipitation threat scores increase during the cooler seasons. A positive correlation exists between TSPs and %R conditions.

WEST division seasonal data are plotted in FIGURE IIb. The LFMII, during the cooler seasons had relatively wet 12 hour biases that increased to very wet values at 48 hours. Summer biases do not vary much. Fourth-order LFM biases for summer, autumn and winter are extremely wet at 12 hours. Winter-time biases become even wetter at 48 hours.

Precipitation threat score trends are the same as that for the EAST. The positive correlation between TSP and %R is quite evident.

In FIGURE IIIa, coarse-mesh model seasonal statistics over the EAST are plotted using the same format as FIGURE IIa. Seven-Layer PE bias trends are similar to those of the LFMII. Biases in summer and transition seasons were wet at 12 hours, decreasing only slightly to relatively wet values at 48 hours. The new convective method that was used in the LFMII in June 1979 was incorporated into the 7LPE in October 1979. This change contributed to an increase in 12 hour biases. It also appears to have reduced 48 hour biases in summer.

The SMG3C is very dry in summer for all periods. This dryness moderates a little during transition seasons. Otherwise, there is an initial very dry bias that increases, but remains relatively dry at 48 hours.

Twelve-hour biases, wet for the 7LPE and very dry for the SMG3C, results in TSP maxima at 24 hours instead of at 12 hours. Small TSPs occur during summer. Seven-Layer PE TSP parallel %R, however, SMG3C's inactive convective method limits scores regardless of %R during spring and fall.

WEST division seasonal data are plotted in FIGURE IIIb. Seven-Layer PE had the same bias trend as the LFMII, i.e., rapidly increasing biases that were very wet by 48 hours. Biases at 12 hours became considerably larger after the new convective method was installed (see seasons prior to autumn 1979). SMG3C bias trend is similar to that observed for the EAST, however, 48 hour biases during the cooler months increase to wet values at 48 hours.

Precipitation threat scores tend to follow %R distribution over the WEST. Dry SMG3C 12 hour biases shift TSP maxima to 24 hours.

For the record, seasonal statistics for .25" and .50" thresholds are presented in TABLES IVa-d. TABLES IVa-b are for the fine-mesh and TABLES IVc-d are for the coarse-mesh models. Station networks cannot correctly represent observed quantitative precipitation distributions especially during warm, convectively active months. However, winter season statistics may be of some value.

Station and forecast amounts greater than threshold values are tabulated as observed and forecast stations. Hits are determined. Precipitation threat scores and bias are calculated using equations (1) and (3) respectively. A no-quantitative precipitation threat score, TSNQ, is calculated using equation (2). Here, N is not the number of stations in the verification division, but the area defined by forecast and observed precipitation. That is,

$$N = F > .01" + O > .01" - H > .01"$$

$$N = F > .25" + O > .25" - H > .25"$$

Instead of %R, percentage observed quantitative precipitation, %QP, is defined,

$$\%QP = O > .25" / O > .01"$$

$$\%QP = O > .50" / O > .25"$$

In general, areal bias characteristics appear to also be true for quantitative precipitation forecasts from both fine- and coarse-mesh models for both EAST and WEST divisions.

Fourth-order LFM has large areal and quantitative biases. One-quarter inch TSP for winter 1982 is larger than that observed for the LFMII during previous two winters. Winter 1982 had larger average observed areal as well as larger one-quarter inch precipitation areas than the other winters.

From another point of view, the quantitative precipitation forecast problem is similar to the areal precipitation forecast problem, finding a small area of precipitation within a larger area. Rather than using the TSP by itself consider bias differences between the LFMII and LFM in the following manner. Define .25" guidance area as,

$$\%G >.25" = O > .25" / (F > .01" + O > .01" - H > .01")$$

For the three winters,

%G >.25"	12HR	24HR	36HR	48HR
WIN80	13.9%	13.8%	13.6%	12.7%
WIN81	14.0%	14.2%	14.3%	13.9%
WIN82	14.9%	13.7%	13.2%	12.5%

Overall guidance value appears quite similar. Bias differences probably determined threat score differences.

TABLE I

PRECIPITATION VERIFICATION: LFM, 7LPE
 90 Station Network (includes 2 Canadians)
 57 Stations east of the Rocky Mountains
 33 Stations westward to the Pacific Ocean

	<u>LFM</u>	<u>DEC76</u> <u>JAN77</u>	<u>7LPE</u>	<u>MAR78</u>
#FCSTS		123		62
EAST.....				
TSP--12HR		37		43
24HR		42		44
36HR		36		40
48HR		30		36
BIAS-12HR		47		76
24HR		71		105
36HR		76		117
48HR		71		127
% RAIN		22.8		17.0
WEST.....				
TSP--12HR		46		44
24HR		34		41
36HR		27		38
48HR		22		31
BIAS-12HR		106		111
24HR		190		180
36HR		254		208
48HR		274		241
% RAIN		11.0		20.0

TABLE IIa

PRECIPITATION VERIFICATION: LFMII, 7LPE

90 Station Network (includes 2 Canadian stations)

57 Stations east of the Rocky Mountains

33 Stations westward from the Rockies to the Pacific Ocean

<u>LFMII</u>	DEC77	JAN78	FEB78	MAR78	APR78	MAY78	JUN78	JUL78	AUG78	SEP78	OCT78	NOV78
#FCSTS									62	51-52	49-50	46-49
EAST.....												
TSP--12HR									21	35	35	44
24HR									20	36	31	48
36HR									17	35	28	45
48HR									17	30	23	37
BIAS-12HR									190	151	73	63
24HR									154	131	84	84
36HR									131	112	75	87
48HR									111	100	69	89
% RAIN									17.9	18.9	12.7	24.0
WEST.....												
TSP--12HR									7	39	35	50
24HR									8	37	33	43
36HR									8	33	32	38
48HR									8	28	25	33
BIAS-12HR									105	134	121	100
24HR									118	161	159	143
36HR									128	181	178	169
48HR									133	183	195	172
% RAIN									11.3	14.0	6.5	20.5

<u>7LPE</u>	DEC77	JAN78	FEB78	MAR78	APR78	MAY78	JUN78	JUL78	AUG78	SEP78	OCT78	NOV78
#FCSTS									58-60	43-52	43-48	43-47
EAST.....												
TSP--12HR									20	29	28	41
24HR									21	33	30	46
36HR									19	33	28	41
48HR									20	29	25	39
BIAS-12HR									194	163	76	71
24HR									205	169	103	110
36HR									185	163	112	118
48HR									175	148	106	119
% RAIN									17.9	19.5	12.7	23.6
WEST.....												
TSP--12HR									5	33	26	45
24HR									7	35	29	44
36HR									8	30	24	37
48HR									8	24	20	33
BIAS-12HR									64	96	84	95
24HR									100	156	173	158
36HR									129	186	250	184
48HR									154	200	292	193
% RAIN									11.4	13.5	6.2	20.8

TABLE IIb

PRECIPITATION VERIFICATION: LFMII, 7LPE

90Station Network; EAST57, WEST33

* New Convective, SATRH=85% in LFMII

** New Verification Network: LFMII...EAST128, WEST62

7LPE....EAST65, WEST36

*** New Convective, SATRH=85% in 7LPE

<u>LFMII</u>	DEC78	JAN79	FEB79	MAR79	APR79	MAY79	JUN79*	JUL79	AUG79**	SEP79	OCT79	NOV79
#FCSTS		55	62	59-60	62	58-60	61	62	60	62	60	
EAST.....												
TSP--12HR	--	47	49	43	31	32	29	39	39	39	49	
24HR	--	45	45	42	33	33	30	42	42	37	47	
36HR	--	43	43	36	32	31	29	40	40	32	44	
48HR	38	39	38	34	29	28	25	34	34	27	39	
BLAS-12HR	--	72	90	112	175	218	183	173	137	137	116	
24HR	--	90	109	98	135	139	105	124	113	113	111	
36HR	--	96	108	90	114	116	87	105	96	96	106	
48HR	78	95	103	87	111	99	74	96	89	89	100	
% RAIN		24.1	22.2	24.7	24.4	17.6	21.5	20.9	16.0	14.4	17.4	
WEST.....												
TSP--12HR	--	46	38	35	31	22	27	37	43	43	44	
24HR	--	42	34	38	30	26	26	33	40	39	39	
36HR	--	38	33	34	25	22	24	28	35	35	34	
48HR	38	37	30	31	23	17	21	20	28	28	29	
BLAS-12HR	--	115	108	95	112	118	137	119	130	123		
24HR	--	161	151	129	124	104	111	119	159	159	167	
36HR	--	172	176	155	156	134	111	171	179	179	184	
48HR	203	172	199	152	144	145	117	241	195	195	198	
% RAIN		26.3	19.0	15.7	13.8	7.0	6.5	12.4	5.9	12.1	14.0	

<u>7LPE</u>	DEC78	JAN79	FEB79	MAR79	APR79	MAY79	JUN79	JUL79	AUG79**	SEP79	OCT79***	NOV79
#FCSTS		54-55	56-60	54-55	60-62	57-58	56-60	58-60	33-56	60-62	57-59	
EAST.....												
TSP--12HR	45	41	42	35	27	29	25	35	29	44		
24HR	47	46	45	40	29	31	28	37	32	42		
36HR	42	41	42	38	28	28	28	35	28	37		
48HR	34	39	38	34	24	26	26	27	22	31		
BIAS-12HR	61	71	80	93	129	141	153	133	180	122		
24HR	86	112	116	109	132	137	149	135	145	129		
36HR	94	120	119	113	128	126	128	119	134	129		
48HR	91	117	120	112	131	118	112	107	127	117		
% RAIN		24.2	22.0	24.9	24.5	17.8	21.2	21.6	15.0	14.6	17.8	
WEST.....												
TSP--12HR	50	44	35	35	26	11	12	19	40	40		
24HR	43	43	33	34	27	18	17	25	38	36		
36HR	40	39	32	30	26	18	16	21	34	32		
48HR	39	35	27	25	24	20	13	15	30	27		
BIAS-12HR	127	104	84	71	70	35	36	70	147	140		
24HR	188	164	167	109	115	86	56	112	181	185		
36HR	204	195	196	156	164	125	80	223	186	213		
48HR	220	205	230	171	193	148	103	353	208	214		
% RAIN		26.3	19.6	15.9	13.4	7.1	6.7	12.5	5.0	13.3	15.0	

TABLE IIc

PRECIPITATION VERIFICATION: LFMII, 7LPE, SMG3C
 Station Network: LFMII...EAST128, WEST62
 7LPE, SMG3C...EAST65, WEST36

<u>LFMII</u>	DEC79	JAN80	FEB80	MAR80	APR80	MAY80	JUN80	JUL80	AUG80	SEP80	OCT80	NOV80
#FCSTS	60	59	58	58-60	55	62	55	58	60	57	60	60
EAST.....												
TSP--12HR	50	49	44	56	52	38	32	30	29	35	43	53
24HR	46	43	40	53	47	40	31	31	30	36	45	52
36HR	40	41	36	48	45	34	28	27	27	33	39	45
48HR	34	35	29	43	40	32	24	23	23	29	35	40
BIAS-12HR	117	105	101	112	123	131	144	152	178	174	122	106
24HR	111	106	98	119	121	105	113	118	113	130	103	99
36HR	103	101	104	122	118	105	95	88	90	106	93	88
48HR	105	105	109	120	125	117	93	86	81	96	93	85
% RAIN	13.5	20.5	16.1	23.6	17.1	19.1	15.8	15.9	18.4	18.7	14.3	15.7
WEST.....												
TSP--12HR	43	48	51	36	36	33	30	18	22	33	41	45
24HR	39	42	44	33	35	34	30	18	23	32	41	38
36HR	34	38	39	32	30	29	23	18	20	27	34	34
48HR	31	33	34	29	26	25	19	16	16	24	33	29
BIAS-12HR	136	140	155	155	144	139	143	83	115	151	134	143
24HR	180	167	192	192	178	142	128	91	108	147	165	198
36HR	201	180	217	202	203	148	143	106	112	152	179	208
48HR	209	188	223	207	219	138	149	125	130	162	167	247
% RAIN	15.9	23.6	23.2	19.1	14.1	17.6	10.6	8.5	8.7	10.5	9.5	12.6

<u>7LPE</u>	DEC79	JAN80	FEB80	MAR80	APR80	MAY80	JUN80	JUL80	AUG80	SEP80 SMG3C	OCT80	NOV80
#FCSTS	57-59	55-60	57-58	51-59	53-56	57-60	44-48	45-53	13-14	11	57-60	53
EAST.....												
TSP--12HR	44	44	35	49	45	34	29	31	28	29	24	36
24HR	44	44	37	50	44	38	30	28	22	37	31	40
36HR	37	38	34	44	42	35	25	26	18	28	30	36
48HR	30	32	27	40	37	31	24	23	23	26	29	30
BIAS-12HR	123	105	103	112	124	162	177	169	164	40	33	51
24HR	127	124	113	129	124	122	136	111	78	51	54	66
36HR	123	125	118	130	136	127	123	85	66	50	61	73
48HR	115	122	120	135	151	131	123	89	62	51	74	68
% RAIN	14.8	20.6	16.0	24.5	18.2	19.3	16.0	17.4	19.0	24.2	15.1	16.0
WEST.....												
TSP--12HR	40	43	50	35	35	34	32	19	5	7	28	40
24HR	37	39	44	33	33	38	28	20	14	13	35	41
36HR	34	36	39	31	29	35	26	17	13	11	35	37
48HR	30	33	36	28	26	29	24	17	13	12	31	35
BIAS-12HR	142	145	158	155	142	141	110	89	26	26	47	87
24HR	198	184	196	208	180	143	118	91	42	84	81	140
36HR	215	210	224	227	208	163	130	109	58	107	112	160
48HR	246	214	224	231	229	164	150	162	103	95	125	179
% RAIN	16.5	23.9	24.5	20.0	14.1	18.1	11.4	8.1	7.9	4.8	9.5	12.3

TABLE IID

PRECIPITATION VERIFICATION: LFMII, SMG3C, LFMStation Network: LFMII, LFM...EAST128, WEST62
SMG3C.....EAST65, WEST36

<u>LFMII</u>	DEC80	JAN81	FEB81	MAR81	APR81	MAY81	JUN81	JUL81	AUG81	SEP81	OCT81	NOV81
#FCSTS	62	62	54	61	60	61	35-39	59	62	60	61	56-57
EAST.....							<u>LFM</u>					
TSP--12HR	42	39	55	47	43	43	31	27	28	30	42	46
24HR	40	38	52	46	44	44	36	32	33	37	45	45
36HR	34	32	44	40	39	40	33	32	31	36	43	38
48HR	27	29	41	33	35	37	27	29	29	31	37	36
BIAS-12HR	102	80	102	109	137	133	267	325	324	284	189	161
24HR	96	76	103	111	131	121	157	174	194	176	152	156
36HR	87	62	94	111	120	122	132	135	155	152	141	154
48HR	84	59	92	108	124	122	114	125	142	137	137	156
% RAIN	14.8	11.2	20.2	15.4	17.9	21.3	21.3	19.8	19.8	15.6	20.3	14.0
WEST.....												
TSP--12HR	46	41	49	44	35	39	35	22	19	29	39	45
24HR	40	37	41	40	32	39	32	24	20	29	37	43
36HR	36	33	33	36	26	34	29	23	18	24	34	33
48HR	31	26	26	31	23	30	26	20	16	24	34	33
BIAS-12HR	144	140	137	149	153	126	211	207	192	240	224	182
24HR	195	176	190	176	193	139	184	143	125	197	214	215
36HR	213	192	204	186	219	141	163	136	133	220	206	247
48HR	235	189	219	179	233	142	139	142	146	234	190	244
% RAIN	14.4	14.0	15.0	18.8	12.5	19.3	10.6	10.0	8.2	9.8	16.6	17.0
<u>SMG3C</u>	DEC80	JAN81	FEB81	MAR81	APR81	MAY81	JUN81	JUL81	AUG81	SEP81	OCT81	NOV81
#FCSTS	61	62	56	62	60	60	60	60	59	47	60	53-54
EAST.....												
TSP--12HR	30	24	37	27	20	16	6	5	5	12	23	30
24HR	33	26	41	33	26	23	11	10	9	17	30	33
36HR	28	25	36	32	23	22	12	11	9	18	27	28
48HR	25	23	33	28	20	21	11	9	9	15	21	25
BIAS-12HR	53	48	58	41	28	23	7	7	7	15	29	44
24HR	83	84	81	71	51	41	18	15	14	30	45	61
36HR	85	100	84	86	56	51	22	20	19	35	49	62
48HR	87	100	90	92	53	54	24	22	22	35	42	65
% RAIN	16.2	12.2	21.0	16.1	17.7	21.1	24.4	20.1	20.3	16.5	20.9	13.9
WEST.....												
TSP--12HR	45	31	44	30	21	20	17	2	2	25	27	38
24HR	45	34	44	39	30	25	22	5	2	25	36	49
36HR	42	31	37	40	26	27	25	6	2	24	34	43
48HR	37	31	33	36	24	26	25	7	4	22	33	43
BIAS-12HR	83	58	64	55	38	26	22	3	3	31	38	62
24HR	135	105	126	99	97	48	53	11	4	56	78	100
36HR	153	126	142	132	135	65	66	14	10	67	98	120
48HR	163	133	153	147	156	81	74	17	15	79	108	141
% RAIN	15.1	14.8	15.7	19.4	13.3	20.6	12.5	9.6	7.8	10.0	16.7	18.5

TABLE IIIa

PRECIPITATION VERIFICATION: LFMII, LFM

	AUT78 LFMII	WIN79	SPR79	SUM79	AUT79	WIN80	SPR80	SUM80	AUT80	WIN81	SPR81	SUM81 LFM	AUT81	WIN82
#FCSTS	146- 151	183- 184	181- 183	181	173	175- 177	173	177	178	182	156- 160	177- 178	170- 173	
EAST.....														
TSP--12HR	38	46	31	42	48	48	30	42	46	44	28	38	47	
24HR	39	44	32	42	43	47	30	43	44	45	34	42	46	
36HR	37	41	31	39	39	42	27	38	38	40	32	39	42	
48HR	31	37	28	33	33	38	23	34	33	35	28	35	37	
BIAS--12HR	96	92	195	141	107	121	159	136	96	127	310	211	123	
24HR	101	101	125	116	104	115	114	112	93	121	177	160	142	
36HR	93	98	104	103	101	115	91	96	85	118	142	148	143	
48HR	88	95	93	95	106	120	86	91	81	119	129	142	144	
TSNP-12HR	82	80	63	82	86	82	74	82	88	82	43	73	81	
24HR	82	78	73	84	85	82	79	85	88	82	68	80	78	
36HR	82	78	76	84	84	80	80	85	86	81	71	80	76	
48HR	80	76	76	83	81	78	79	83	85	79	71	78	74	
% RAIN	18.6	23.7	20.4	15.9	16.8	20.0	16.7	16.2	15.2	18.2	20.2	16.7	20.4	
WEST.....														
TSP--12HR	43	40	27	42	48	35	24	40	45	40	24	38	41	
24HR	39	38	26	38	42	34	24	37	40	37	25	37	37	
36HR	35	35	24	33	37	30	20	32	34	32	23	33	33	
48HR	30	33	20	27	33	27	17	29	28	28	20	31	31	
BIAS-12HR	115	107	122	125	145	146	115	143	140	141	203	212	207	
24HR	152	148	108	155	180	170	110	172	187	166	147	210	242	
36HR	174	168	123	180	199	183	121	182	203	177	142	225	254	
48HR	180	174	125	204	206	185	135	196	214	178	143	220	268	
TSNP-12HR	87	84	89	90	78	77	87	88	85	80	82	77	70	
24HR	84	80	89	87	71	75	88	85	80	77	85	77	63	
36HR	30	76	88	84	65	76	86	83	76	73	85	74	58	
48HR	78	75	87	80	61	69	84	81	72	70	84	73	55	
%RAIN	13.6	16.2	8.6	10.7	21.2	17.0	9.2	10.8	14.4	16.9	9.4	14.4	19.4	

TABLE IIe

PRECIPITATION VERIFICATION: LFM, SMG3C

Station Network: LFM.....EAST128, WEST62
SMG3C.....EAST65, WEST36

<u>LFM</u>	DEC81	JAN82	FEB82
#FCSTS	62	57-58	50-54
EAST.....			
TSP--12HR	47	48	47
24HR	48	46	45
36HR	43	41	42
48HR	36	38	35
BIAS-12HR	120	123	127
24HR	134	147	145
36HR	131	153	144
48HR	125	158	148
% RAIN	19.5	23.1	18.4
WEST.....			
TSP--12HR	46	38	39
24HR	41	34	36
36HR	37	31	31
48HR	33	30	29
BIAS-12HR	189	230	203
24HR	221	271	234
36HR	229	286	249
48HR	244	293	271
% RAIN	20.4	20.3	17.3
<u>SMG3C</u>	DEC81	JAN82	FEB82
#FCSTS	62	57-58	54
EAST.....			
TSP--12HR	32	38	34
24HR	35	38	35
36HR	33	35	32
48HR	30	33	27
BIAS-12HR	48	66	47
24HR	75	103	73
36HR	87	112	83
48HR	89	108	88
% RAIN	20.9	22.9	20.3
WEST.....			
TSP--12HR	44	38	36
24HR	45	41	40
36HR	42	39	38
48HR	36	35	37
BIAS-12HR	82	98	68
24HR	123	166	114
36HR	142	186	139
48HR	150	195	158
% RAIN	21.4	22.0	18.5

TABLE IIIb

PRECIPITATION VERIFICATION: 7LPE, SMG3C

	AUT78 7LPE	WIN79	SPR79	SUM79	AUT79	WIN80	SPR80	SUM80	AUT80 SMG3C	WIN81	SPR81	SUM81	AUT81	WIN82
#FCSTS	129- 146	170- 177	171- 178	150- 177	165- 175	162- 175	103- 114	121- 124	179	182- 183	179	179	160- 161	173- 174
EAST.....														
TSP--12HR	32		39	27	35	41	43	30	30	31	21	5	22	35
24HR	37		43	30	37	42	44	28	35	34	27	10	27	36
36HR	35		40	28	33	36	40	25	32	30	26	10	25	34
48HR	32		37	26	27	30	36	23	29	27	23	10	20	30
BIAS-12HR	105		82	141	144	109	131	172	41	54	30	7	29	54
24HR	130		112	139	136	121	125	116	59	82	53	16	45	84
36HR	132		117	126	129	122	131	98	64	89	63	20	48	95
48HR	126		116	120	119	119	138	99	69	92	65	22	46	95
TSNP-12HR	79		78	68	79	83	78	72	86	86	84	79	85	83
24HR	78		76	70	80	82	79	78	87	84	83	79	85	79
36HR	77		74	71	81	80	76	78	86	82	81	78	84	77
48HR	75		72	71	79	78	73	78	84	81	80	78	82	75
% RAIN	18.8		23.8	20.4	15.9	17.3	20.7	17.1	16.2	16.3	18.3	21.6	17.3	21.3
WEST.....														
TSP--12HR	37		39	15	37	45	35	25	33	40	24	8	31	40
24HR	38		37	19	35	41	34	24	38	41	32	12	39	42
36HR	32		34	19	31	36	32	21	35	37	32	14	36	39
48HR	27		30	18	27	33	28	20	32	34	29	15	35	36
BIAS-12HR	93		88	45	133	150	146	94	66	68	39	11	46	84
24HR	160		149	81	173	193	177	99	112	122	79	27	83	136
36HR	194		184	118	201	217	198	114	137	140	107	35	101	156
48HR	209		203	141	224	227	206	150	152	149	124	40	116	168
TSNP-12HR	87		85	91	87	75	77	88	91	88	84	91	88	82
24HR	82		79	89	84	67	73	88	90	85	82	90	87	77
36HR	78		74	87	79	60	69	87	88	81	79	90	84	73
48HR	76		70	85	75	56	65	84	86	79	76	89	83	69
% RAIN	13.4		16.2	8.6	11.7	21.9	17.5	9.4	10.3	15.2	17.8	10.0	15.3	20.7

TABLE IVa

PRECIPITATION VERIFICATION: .25" THRESHOLD
LFMII, LFM

	AUT78 LFMII	WIN79	SPR79	SUM79	AUT79	WIN80	SPR80	SUM80	AUT80	WIN81	SPR81	SUM81 LFM	AUT81	WIN82
#FCSTS	146- 151	183- 184	181- 183	181	173	175- 177	173	177	177	178	182	156- 160	177- 178	170- 173
EAST.....														
TSP--12HR	26	30	15	32	34	37	15	29	36	26	16	25	40	
24HR	24	30	14	33	30	34	13	30	36	26	15	28	37	
36HR	20	24	12	30	25	29	10	24	26	22	11	23	34	
48HR	15	19	9	24	19	25	9	16	21	18	8	17	26	
BIAS-12HR	102	98	157	99	87	91	90	100	89	72	364	226	128	
24HR	103	113	53	89	101	118	66	88	95	97	57	92	131	
36HR	107	134	52	93	114	120	49	75	84	101	51	80	141	
48HR	100	128	47	85	123	119	48	73	76	101	49	71	140	
TSNQ-12HR	76	74	69	78	86	79	74	78	87	79	60	71	84	
24HR	75	74	75	77	84	74	72	77	86	75	80	80	84	
36HR	72	68	73	74	81	72	71	75	84	73	76	79	83	
48HR	71	66	71	72	80	71	71	72	83	73	75	78	81	
% QP	26.7	28.7	34.5	33.2	19.7	31.9	34.6	30.2	19.0	29.9	35.1	30.8	22.6	
WEST.....														
TSP--12HR	23	17	9	19	27	17	7	21	31	15	9	30	31	
24HR	21	17	8	15	23	17	6	22	23	16	8	26	24	
36HR	16	12	9	14	18	15	8	14	20	14	7	19	19	
48HR	14	11	4	10	15	12	5	12	16	12	9	15	16	
BIAS-12HR	124	110	62	67	119	54	28	71	129	46	89	146	177	
24HR	201	210	52	121	205	103	35	130	192	96	31	141	227	
36HR	201	229	58	129	218	109	50	120	197	91	51	117	254	
48HR	174	220	52	168	225	123	39	133	214	108	57	87	290	
TSNQ-12HR	78	85	86	84	83	90	92	86	85	88	88	86	86	
24HR	74	82	85	80	78	88	91	84	82	85	90	85	83	
36HR	75	81	86	82	78	88	91	84	83	86	87	86	81	
48HR	77	82	86	80	77	87	92	83	81	85	89	87	78	
% QP	22.5	14.4	18.2	21.6	21.3	16.2	3.4	6.7	19.4	19.4	17.2	23.1	20.5	

TABLE IVb

PRECIPITATION VERIFICATION: .50" THRESHOLD
LFMII, LFM

	AUT78 LFMII	WIN79	SPR79	SUM79	AUT79	WIN80	SPR80	SUM80	AUT80	WIN81	SPR81	SUM81 LFM	AUT81	WIN81
#FCSTS	146- 151	183- 184	181- 183	181	173	175- 177	173	177	178	182	156- 160	177- 178	170- 173	
EAST.....														
TSP--12HR	17		22	8	23	23	24	6	21	28	14	12	18	30
24HR	15		21	8	25	20	26	6	19	26	17	7	14	26
36HR	11		18	6	24	18	23	5	12	18	14	4	11	26
48HR	8		11	4	17	12	18	5	10	15	12	3	8	17
BIAS-12HR	91		80	94	60	56	65	38	64	78	37	274	188	114
24HR	108		127	26	74	82	100	42	66	83	73	21	54	166
36HR	112		129	31	85	103	112	34	54	72	78	21	50	137
48HR	92		128	28	72	93	108	35	54	66	77	23	38	134
TSNQ-12HR	57		57	57	65	57	57	59	62	65	62	57	60	61
24HR	53		47	54	53	61	57	52	57	64	60	55	61	59
36HR	54		52	51	50	59	54	50	55	62	58	54	58	57
48HR	54		48	50	49	62	51	50	55	62	59	53	60	55
% QP	46.7		51.3	55.8	57.1	45.4	52.7	54.4	49.8	42.6	47.7	55.2	48.0	47.9
WEST.....														
TSP--12HR	19		9	2	8	21	10	0	18	31	5	5	19	25
24HR	16		7	2	7	21	14	0	17	18	4	2	17	21
36HR	11		8	0	8	14	13	0	9	15	7	0	6	15
48HR	8		4	0	6	13	7	2	12	11	7	1	7	12
BIAS-12HR	134		133	38	38	80	25	17	52	113	17	36	92	137
24HR	220		222	22	63	169	54	14	76	178	42	2	95	168
36HR	192		278	30	88	178	57	43	74	168	48	22	48	220
48HR	179		247	22	123	158	70	26	111	222	63	36	58	307
TSNQ-12HR	67		71	64	67	69	76	73	69	70	75	71	73	69
24HR	65		73	67	72	68	79	75	73	63	77	67	71	70
36HR	67		71	66	70	65	79	72	70	64	77	65	73	65
48HR	64		71	67	69	69	77	75	68	58	77	61	69	57
% QP	35.2		25.5	39.8	37.3	41.8	30.5	27.6	38.5	41.8	29.4	41.0	37.2	42.2

TABLE IVc

PRECIPITATION VERIFICATION: .25" THRESHOLD
7LPE, SMG3C

	AUT78 7LPE	WIN79	SPR79	SUM79	AUT79	WIN80	SPR80	SUM80	AUT80 SMG3c	WIN81	SPR81	SUM81	AUT81	WIN82
#FCSTS	129- 146	170- 177	171- 178	150- 177	165- 175	162- 175	103- 114	121- 124	179	182- 183	179	179	160- 161	173- 174
EAST.....														
TSP--12HR	21	23	10	27	27	29	6	21	23	10	1	11	23	
24HR	23	27	13	29	27	31	7	27	23	15	5	16	24	
36HR	19	21	11	21	18	25	6	18	21	13	4	13	22	
48HR	18	18	10	15	15	21	5	16	19	11	2	10	18	
BIAS-12HR	118	93	86	79	69	64	26	36	52	23	2	19	48	
24HR	148	143	68	88	99	97	28	65	81	45	13	41	77	
36HR	159	148	75	90	99	98	33	62	83	55	13	40	94	
48HR	145	157	72	85	105	109	32	72	85	63	14	36	108	
TSNQ-12HR	79	72	72	80	86	82	81	74	84	72	66	73	80	
24HR	74	70	75	78	85	78	77	74	83	73	66	72	81	
36HR	72	67	72	75	82	76	75	72	83	72	67	72	80	
48HR	72	65	71	74	82	74	75	70	83	71	66	72	77	
% QP	26.5	28.4	34.3	32.5	20.0	31.2	34.1	29.5	19.4	29.1	34.5	29.4	22.7	
WEST.....														
TSP--12HR	16	19	3	14	22	9	2	17	19	7	2	13	23	
24HR	17	16	5	18	22	17	0	20	21	11	4	21	25	
36HR	12	15	10	15	19	13	0	16	16	15	7	23	19	
48HR	12	13	6	14	16	12	0	17	17	11	7	19	18	
BIAS-12HR	72	63	10	41	85	23	2	53	63	20	6	32	81	
24HR	150	172	38	118	195	69	8	133	142	69	13	87	158	
36HR	148	154	80	129	207	86	20	155	151	89	19	125	198	
48HR	157	193	88	179	244	114	14	186	176	103	31	145	249	
TSNQ-12HR	79	88	85	90	86	91	92	81	81	81	84	80	82	
24HR	78	84	85	84	81	91	91	77	79	80	85	78	81	
36HR	80	87	85	84	82	89	91	77	78	81	86	78	77	
48HR	81	87	85	83	79	89	93	76	78	81	85	76	75	
% QP	22.6	14.4	18.3	20.5	20.8	16.2	13.1	21.5	20.2	20.0	15.8	21.8	19.7	

TABLE IVd

PRECIPITATION VERIFICATION: .50" THRESHOLD
7LPE, SMG3C

	AUT78 7LPE	WIN79	SPR79	SUM79	AUT79	WIN80	SPR80	SUM80	AUT80 SMG3C	WIN81	SPR81	SUM81	AUT81	WIN82
#FCSTS	129- 146	170- 177	171- 178	150- 177	165- 175	162- 175	103- 114	121- 124	179	182- 183	179	179	160- 161	173- 174
EAST.....														
TSP-12HR	11	20	5	18	17	19	2	15	12	5	1	6	14	
24HR	14	20	6	22	18	20	3	17	14	8	3	7	15	
36HR	11	16	6	13	13	17	3	13	13	7	1	5	14	
48HR	10	11	5	8	9	14	3	11	10	7	1	6	12	
BIAS-12HR	98	76	46	50	51	39	3	31	50	14	1	16	48	
24HR	131	134	34	67	79	76	11	76	95	49	11	39	84	
36HR	154	141	45	82	74	91	17	78	103	59	12	35	111	
48HR	136	155	39	72	85	100	15	92	94	75	13	39	136	
TSNQ-12HR	56	57	57	55	59	56	55	56	58	57	47	52	56	
24HR	57	53	54	54	61	53	52	51	56	53	47	49	53	
36HR	52	52	53	49	61	49	51	51	54	53	46	49	52	
48HR	54	49	54	49	57	50	52	49	56	51	46	49	50	
% QP	47.3	51.4	55.5	54.5	46.3	53.4	54.3	46.2	41.4	45.1	53.4	49.5	44.6	
WEST.....														
TSP--12HR	8	10	0	13	15	2	0	10	15	3	2	1	10	
24HR	11	12	0	17	21	4	0	7	13	2	0	14	19	
36HR	8	5	0	11	18	3	0	7	11	4	2	15	13	
48HR	6	5	2	9	15	6	0	8	9	7	2	11	16	
BIAS-12HR	48	36	9	20	40	10	0	42	54	10	7	19	59	
24HR	108	114	22	90	129	30	0	88	133	42	4	67	141	
36HR	90	94	35	80	150	36	7	138	172	64	9	123	182	
48HR	130	153	34	160	182	77	0	130	191	101	21	125	253	
TSNQ-12HR	70	79	61	73	68	68	70	62	65	71	56	62	63	
24HR	72	81	63	73	71	73	75	65	62	72	57	65	65	
36HR	72	78	67	73	68	73	73	62	58	72	59	62	63	
48HR	76	76	71	67	67	72	74	67	57	70	55	65	62	
% QP	35.9	26.0	39.4	35.4	44.4	33.5	29.6	40.3	39.8	30.7	44.7	39.0	40.5	

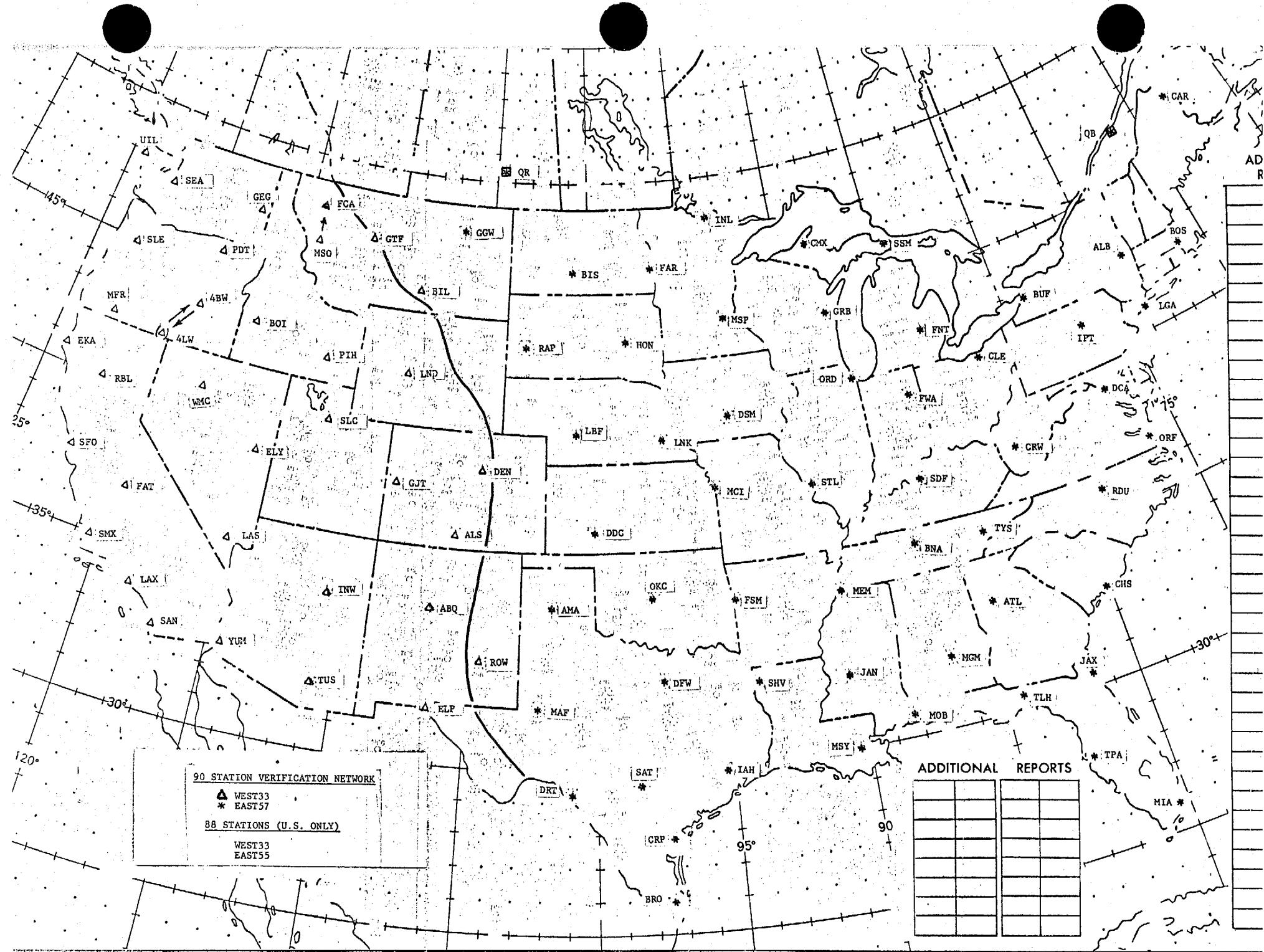


FIGURE Ia

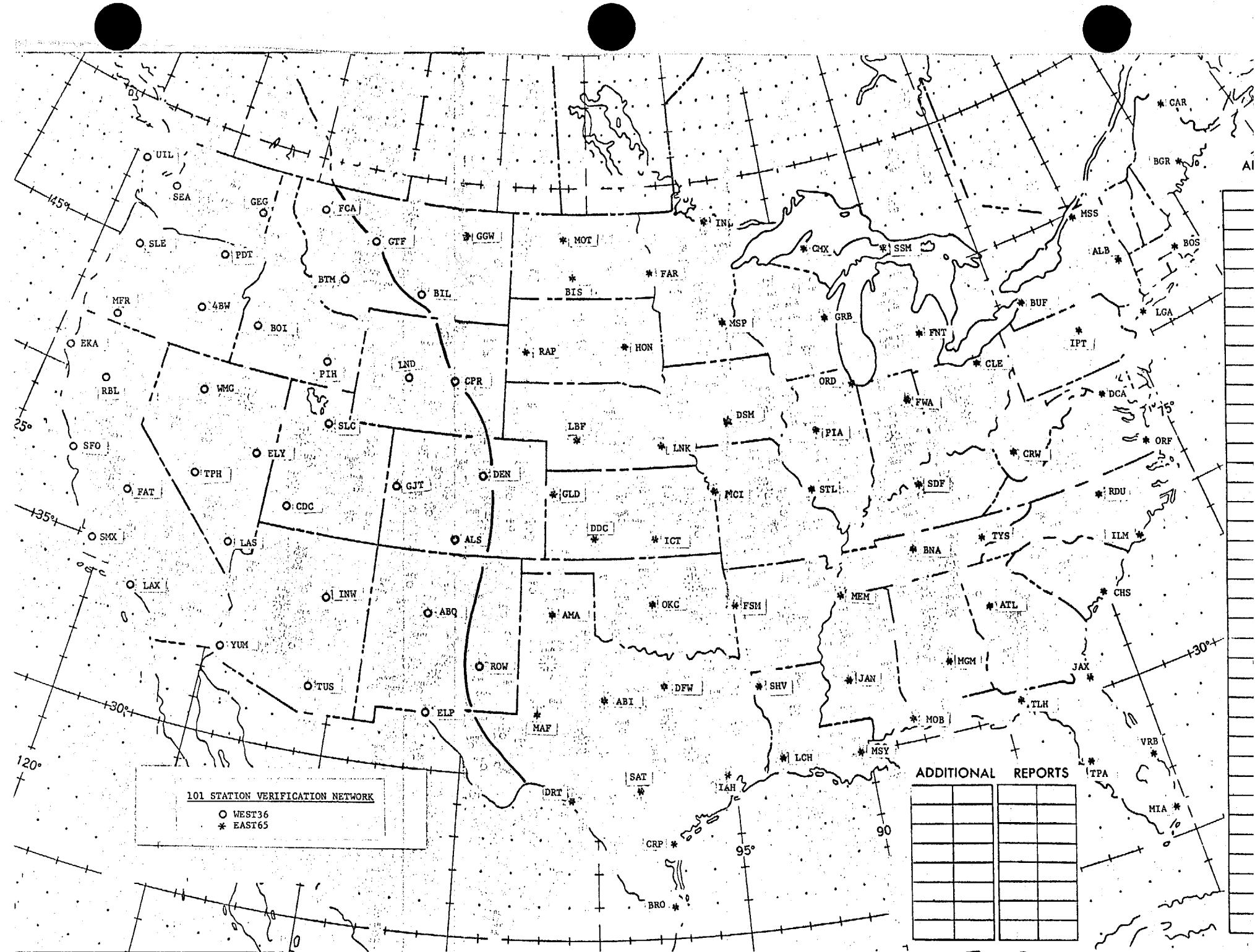


FIGURE I b

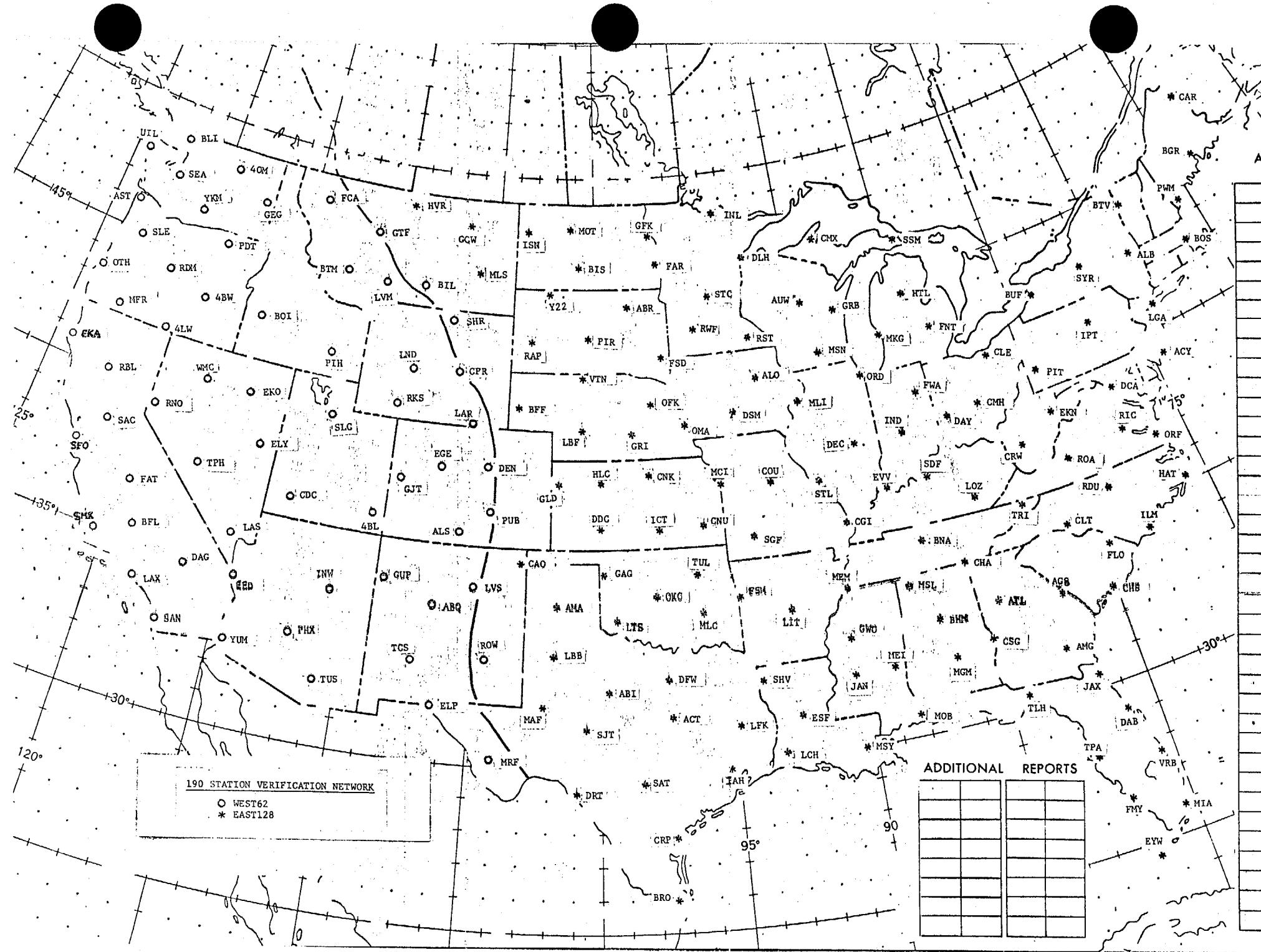


FIGURE Ic

FIGURE IIa

FINE-MESH: EAST

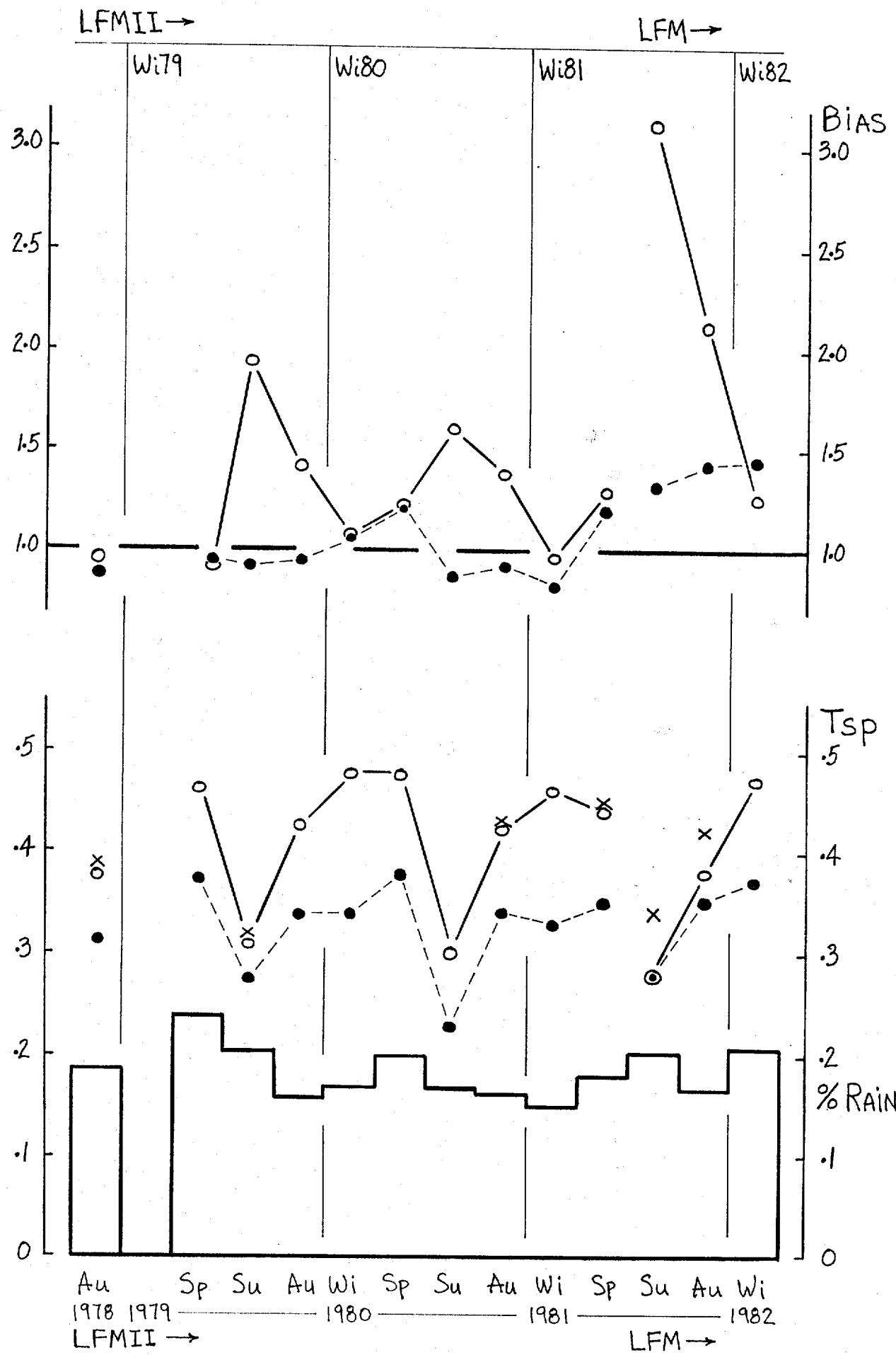
(12HR(○), 48HR(●), %RAIN(COL)
MAX TSP(X))

FIGURE IIb

FINE-MESH: WEST

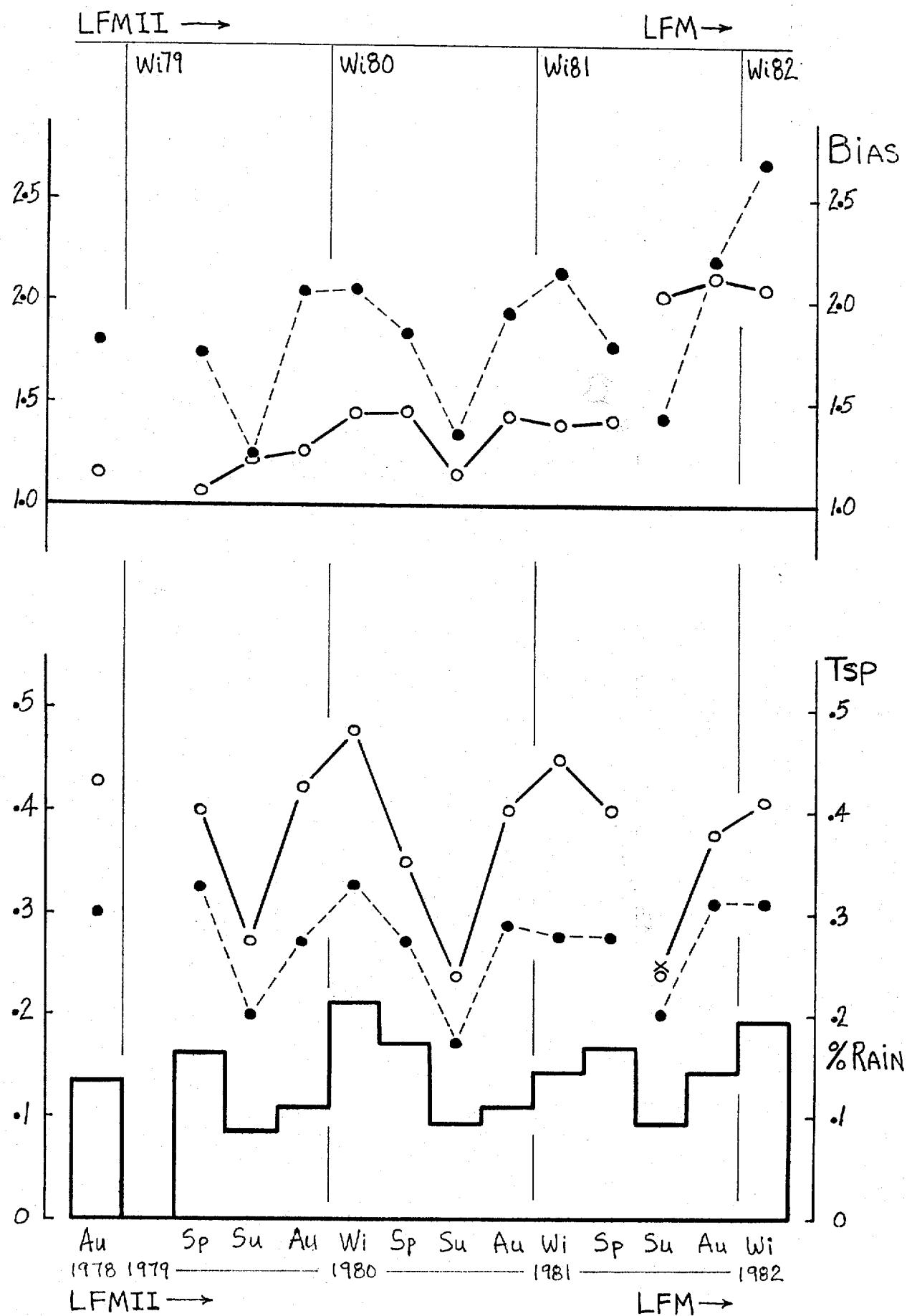
12HR(○), 48HR(●), %RAIN(COL)
MAX TSP(X)

FIGURE IIIa

COARSE-MESH: EAST

12HR(○), 48HR(●), %RAIN(COL)

MAX TSP(X)

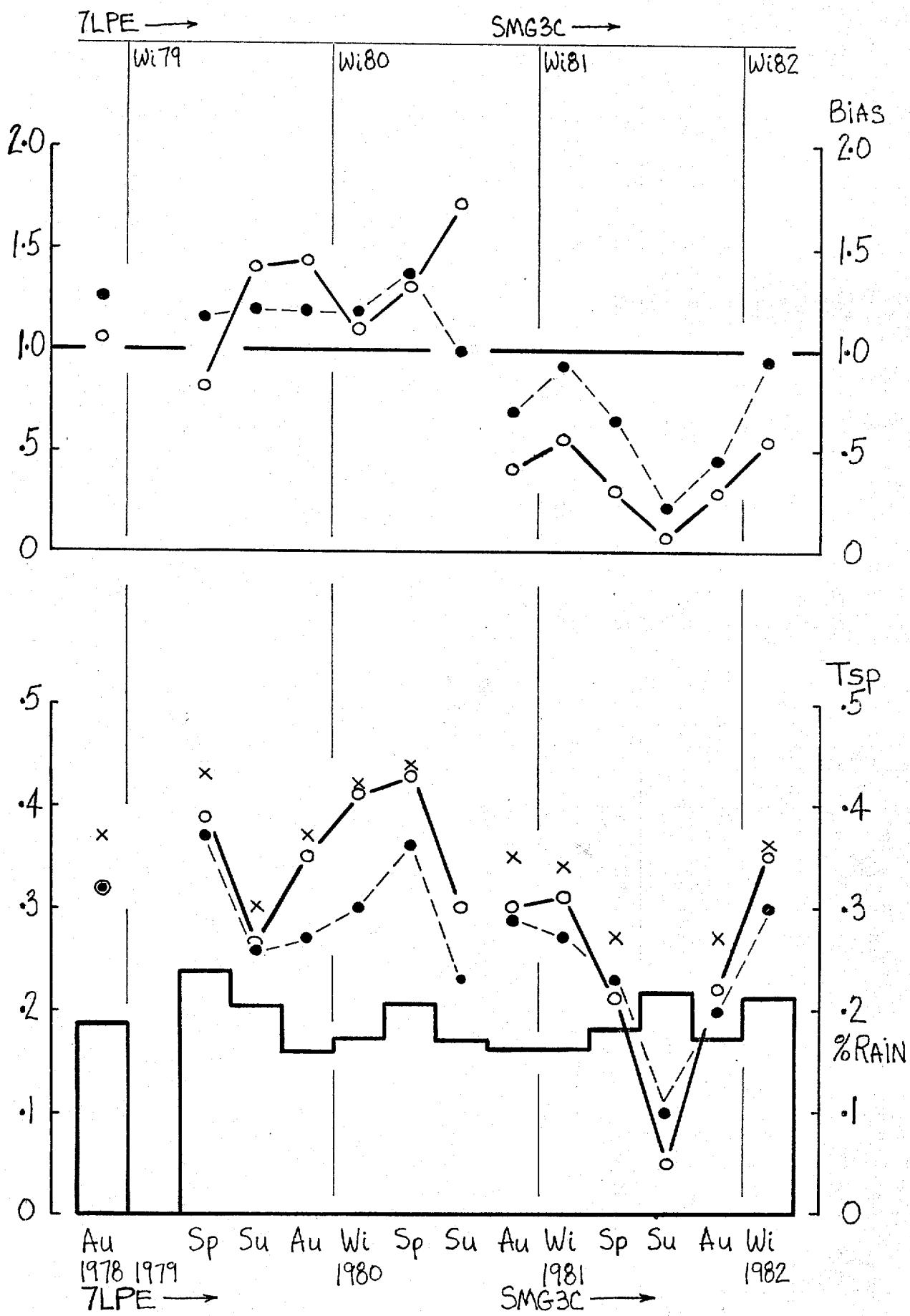


FIGURE IIIb

COARSE-MESH: WEST

12HR(○), 48HR(●), %RAIN(COL)
MAXTSP(X)